Inventor: Sines , E.
Serial No. 08/940,179

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PATENT APPLICATION
Navy Case No. 78,465

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of: Sines

Serial No. 08/940,179

Filed: September 30, 1997

For: ELECTRICAL POWER COOLING
DEVICES TECHNIQUE

Examiner: Mia, A.

Group Art Unit: 2832

DECLARATION IN SUPPORT OF THE APPLICATION OF SINES PURSUANT TO 36 CFR § 1.131

Commissioner of Patents and Trademarks
Washington, DC 20231

Sir:

I, William E. Howell, hereby declare that:

1. I am employed as Chief Scientist in the Tactical Electronic Warfare Division of the Naval Research Laboratory (NRL).

2. I further declare that I have a PhD in Physics granted in 1984 by Catholic University of America. For the past 25 years I have worked in the field of electronic warfare. I have authored or co-authored more than 60 reports, papers and articles in the field of physics and electronic warfare.

3. I further declare that I have reviewed the application of Mr. Eddie Sines entitled ELECTRICAL POWER DEVICES COOLING TECHNIQUES, Serial No. 08/940,179,

filed in the United States Patent and Trademark Office on September 30, 1997. Further, I have reviewed the following patents:

(a) U.S. Patent No. 5,158,690; THERMOPHORETIC FILTERING OF LIQUIDS; J. Batchelder et al.; October27, 1992.
(b) U.S. Patent No. 5,091,666; STATOR COOLING SYSTEM FOR ELECTRICAL MACHINERY; E. Jarczynski, February 25, 1992.
(c) U.S. Patent No. 4,082,916; ENCAPSULATED ELECTRICAL INDUCTIVE APPARATUS; A. Jaklic et al.; April 4, 1978.
(d) U.S. Patent No. 3,810,303; METHOD OF MAKING ELECTRICAL TRANSFORMER MEANS; J. Hoell; May 14, 1974.

4. I hereby declare that the above-stated U.S. patents do not teach or suggest the use of a thermally conductive strip of high modulus carbon graphite laminate material as claimed by the applicant in the above-stated application.

5. Transformers and motors have unique thermal issues associated with tightly-wound coils and compact designs. Present materials used for thermal control in coils have had limited success because the materials applied have large electrical conductivity, i.e., copper and aluminum. This high electrical conductivity causes unwanted heating due to the eddy currents that are generated by time-varying magnetic fields. A proper match of thermal material to the transformer/motor application is needed to resolve these important issues.

6. Conventional transformer design has changed very little over the past 25 years and is inhibited by the cooling limitation of tightly-wound coils. There have been attempts in the past to modify the coil configuration to reduce the thermal load, however, these techniques tend to increase eddy current losses which in turn decreases efficiency. The unfulfilled need for higher-efficiency in transformers has been cited by the U.S. Environmental Protection Agency,

Atmospheric Pollution Prevention Division, in a paper entitled TRANSFORMING DOLLARS INTO SENSE: THE ECONOMIC AND ENVIRONMENTAL BENEFITS OF HIGH-EFFICIENCY TRANSFORMERS, prepared under contract no. 68-D4-0088 by ICF Inc. (see Attachment 1) and Hammons et al., FUTURE TRENDS IN ENERGY-EFFICIENT TRANSFORMERS, IEEE Pwr Engr Rev, pp. 5-16, Jul 98 (Attachment 2). Based on this paper, cooling techniques that increase eddy current losses are not acceptable. The novel cooling technique taught by the above-stated application is a large step in fulfilling this unsatisfied need and has a very wide application in power transformers and motors where: reduced coil operating temperatures, reduced transformer size, and extended operating life are all desired with no increase in eddy current losses. The designs taught by the above-stated application will translate into new applications where lightweight high power density electrical systems are needed while reducing the cost and volume of these applications.

7. The superior thermal transport properties provided by pitch-derived graphite fiber in a composite configuration has provided an almost ideal interface for this application. Some pitch-derived fibers can provide thermal conductivity greater than 1000 W/mK, which is about twice that of copper. Pitch-derived graphite fibers by themselves are structurally weak and must be added to a polymer-matrix composite for strength. The advantages of using these strengthen pitch-derived graphite fibers composites are: low specific gravity, high electrical resistivity, chemical resistance, and heat conduction nearly 2X better than copper. A very important point to note is, that they are inherently better to use in inductor

applications , such as in that claimed by the applicant, because they behave more like an electrical insulator than an electrical conductor; the mechanisms responsible for their electrical and thermal conduction are different.

8. Because of material availability, the Applicant utilized a high modulus carbon graphite laminate material, type K1100 manufactured by Amoco Performance Products, Inc.(APP), a subsidiary of Amoco Corporation of Chicago, IL. Attachments 3 through 9 show the characteristics of this material and its relationship to other materials used as heat transfer components. This information comes from a brochure distributed by APP. The continuous carbon fibers in such materials as K1100 exhibit conductivity strongly in the longitudinal direction of the fibers and they conduct very little electricity in that direction. This property makes these fibers, as exemplified by the K1100, very useful for conducting heat from the interior of a tightly-wound coil to the outside of the coil. The longitudinal thermal conductive properties of these types of fibers are based on their lattice similarity to diamond and/or highly oriented pyralytic graphite and on the microstructure of the fibers. If two fibers are touching each other along the length, traverse heat flow from one fiber to the other is only on the order of 5% of the total heat within the fiber. Approximately 95% of the heat passes longitudinally to the end of the fiber. The highest thermal conductivity in the thermal strip is attained when all of the fibers are aligned in a unidirectional way.

9. When metal wires are in direct contact with the high modulus carbon graphite material, they exhibit a very low thermal contact impedance which allows heat to pass

easily to the high modulus carbon graphite laminate material. Heat is then conducted rapidly out of the device where the heat can be dissipated by convection or radiation into the ambient atmosphere. The high modulus carbon graphite laminate materials are 4X more conductive than any of the metals ever atempted in such an arrangement.

10. When any conductor is placed into a changing magnetic field of a transformer, parasitic eddy-currents are generated inside of the conductor. Even very thin copper will produce large eddy currents when placed into a high frequency flux field because it is a good conductor of electricity, unlike the high modulus carbon graphite laminate material, such as K1100, which has low electrical conductivity. These eddy-currents are power losses. The eddy-current power losses are proportional to the lamination material's conductivity; the higher the laminations material's electrical conductivity, the higher its eddy-current losses. Copper material placed lengthwise inside a transformer has an eddy-current power loss ~100X greater than that of high modulus carbon graphite laminate material.

11. The above-stated application uses thermal grease to displace poor thermally conducting materials like potting compound and air during coil construction. Adding thermal grease enhances thermal character of the coil structure filling the gaps between the round (wire) conductors, thus minimizing hot spots during operations. This approach also ensures good thermal contact between coil windings and the high thermal conducting carbon strips.

12. The use of a high thermal conductivity carbon graphite laminate material in the coil windings of a multi-conductor electrical device, as taught by the above-stated

application, is a phenomenal advance in the cooling design of industrial electrical devices. This novel cooling technique provides a means for improvements in transformer power handling or reductions in size, and other electrical devices. Analysis of information from tests of the above-stated applications prototypes transformer devices demonstrates power density improvements of approximately 2X, as indicated from the tests, using the high thermal conductivity carbon graphite laminate material.

13. TECHNICAL EVALUATION OF THE *JARCYNSKI PATENT AS RELATES TO THE ABOVE-STATED APPLICATION*

(A) The *Jarcynski* patent is based on cooling motor laminations through the use of a forced liquid cooling system having cooling passageways designed into the outer casing of the motor. *Jarcynski* provides an additional thermal path which is defined as a preferential solid path through the use of thermally conductive laminations. These thermally conductive laminations are made of a non-magnetic material said to be copper. *Jarcynski* points out that one skilled in the art would be capable of selecting a suitable material for both the electromagnetic stator core and the solid radial thermal transfer paths, although it is noted that it does not teach a high modulus, high thermal conductivity carbon graphite laminate material even though it was available at the time the application was filed.

(B) The technical approach taught by *Jarcynski* to solve thermal problems in a high power electrical motor is limited to the thermal interface materials and problems related with the application of copper in high density high frequency magnetic fields and fails to recognize that most of the heat generated in the motor is through the I^2R power losses

in the motor windings and not the motor laminations, this is very important. Heat in the motor windings is trapped and must be conducted through the core laminations in order to be dissipated to ambient air. Even though the thermally conductive laminations made of copper are in close proximity to the motor windings they do not go into the motor coil bundle or windings. In addition, the large time varying magnetic flux present next to the motor windings would cause the electrically conductive laminations made of copper to heat up by induction making them inefficient at this critical thermal interface. The critical difference between *Jarczynski* and the above-stated application is that the high modulus, high thermal conductivity, carbon graphite laminate material, in the case of the above-stated application -- K1100, thermal interface provides a direct path from the interior of the motor or transformer windings to the outside of the case, thereby cooling the windings very efficiently and minimizing the migration of heat into the motor or transformer laminations. Thus increasing the current density to the windings and hence raising the power density of the electrical device. The technique taught in the above-stated application removes and shunts the heat out of the system before absorption.

(C) Even though the copper laminations taught by *Jarczynski* are thin, they are exposed to rapid changes in magnetic flux which will cause the thermally conductive lamination on both ends next to the fast changing magnetic flux to become a source of heat and not a sink. The high modulus carbon graphite laminate material would not suffer this reduction in performance at the critical thermal interface because high modulus carbon graphite laminate is not strongly affected by fast changing magnetic flux. Also, a high modulus carbon graphite

laminate material has a thermal conductivity ~2.4 times better than copper. Given the distance which heat must travel to be dissipated into ambient atmosphere, the thermal resistance would be at least ~2.4 times less than copper, so the amount of the I^2R heat that can be removed would be considerably more.

(D) The teaching of *Jarczynski* uses pumped liquid to dissipate the heat by pumping chilled coolant through multiple passageways. The power density of a system should be judged by the total system volume and all support systems. The *Jarczynski* system would be much more bulky and have higher risk of failure than the above-stated application because it depends upon the coolant being mechanically pumped to remove the heat whereas the above-stated application thermal interface is using a passive heat removal system which can be supported with a simple fan attached to the shaft of the motor and be air cooled , thereby making the cooling system self-supporting and more compact. Air cooling is suitable in the above-stated application because the thermal conductivity of the high modulus carbon graphite laminate material's thermal interface provides a high temperature at the electrical devices case or fin tips, thereby making the air cooled interface more effective at heat dissipation. It is known that at higher temperature, more heat can be dissipated from the fins.

14. TECHNICAL EVALUATION OF THE *HOELL PATENT AS RELATES TO THE ABOVE-STATED APPLICATION*

(A) As previously stated, the *Jarczynski* patent removes heat with the use of copper, so does the *Hoell* patent with the inherent eddy-current problems as stated above. Differing from *Jarczynski*, *Hoell* uses a wide copper strip placed through the coil where the

changing magnetic field is strong and it is used in a passive mode. *Hoell* has also connected the thermal interface directly to the laminations to sink the heat into the inductor. This raises its temperature unwantedly. In addition, *Hoell* reduces thermal interface by placing a rubber insulator over the copper strip to minimize electrical failure. This rubber interface reduces the thermal effectiveness of the total system defeating the thermal interface purpose. This is unlike the teaching of the above-stated application which needs no added electrical isolation from the windings of the coil. The assembly and construction of the thermal interface taught by *Hoell* produces a rectangular slot first between the windings with wide tolerances used to enable the insertion of the cooling strip. The gaps or tolerances needed to conduct heat efficiently from the coil to the copper strip thermal interface impedes the flow of heat out of the coil. Using the filler coat, as taught by *Hoell*, the effectiveness of the thermal interface would be reduced. The above-stated application's thermal interface is placed directly into the coil with no insulators between the wire and the heat produced by the I^2R losses in the copper wires. Where very high performance is required, the above-stated application uses a thermal grease to displace air, not the thermal materials taught by *Hoell*. The *Hoell* patent uses only one copper thermal strip on each side of the transformer. This application is not very effective because the windings are heating up in the areas not covered by the copper thermal strips, thereby, allowing the conductors to overheat and exceed the thermal rating of the wire insulation. A major difference between the thermal interface taught by the *Jarczynski* and *Hoell patents* and the above-stated application is the thermal interface in the above-stated application provides multi-paths that do not produce

unwanted eddy current losses while providing direct cooling to the internal parts of the coil winding layers because the above-stated application teaches an electrical insulator instead of a metal strip for conducting heat. The above-stated application teaches a direct thermal interface at the 12:00, 3:00, 6;00 and 9;00 o'clock positions on different winding layers providing multi-paths for the heat to flow creating short thermal paths for the heat generated on different layers to pass directly out of the coil by conduction and radiation. Also, the above-stated applications thermal interface does not degrade the electrical devices core material by sinking the heat to this interface.

15. TECHNICAL EVALUATION OF THE *BATCHELDER ET AL. PATENT AS RELATES TO THE ABOVE-STATED APPLICATION*

(A) *Batchelder et al.* teaches the use of a thermocooler to assist in the filtering of micro-particles from pumped liquids. The teachings of *Batchelder et al.* does not encompass the same field of art as the above-state application. The applicant's claimed thermocooler is designed to be used to remove heat or apply heat, depending on direction, and to my knowledge there is no teaching of using a thermocooler to assist in the cooling of electrical devices such as transformers. In the past, the use of a thermocooler would have been impracticable because there was no teaching of a direct way to cool the internal coil windings where the heat builds up. The high modulus carbon graphite laminate material interface along with a high performance potting interface provides a strong thermal path for the thermocooler to cool the internal windings. This is a radical approach to transformer cooling and only works if there is the superior cooling interface provided by the high modulus carbon graphite laminate

strips interleaved into the coil windings. It is noted that the thermocooler is outside of the strong region of the magnetic field of the transformer and is unaffected.

(B) The thermocooler's provide active cooling to the windings in through the interface to lower the temperature of the copper conductors. This novel technical approach addresses one of the primary sources of transformer temperature rise, namely I^2R power losses in the copper conductors. Thermocooler's may also be applied to the magnetic laminations to remove this heat also.

(C) Present day transformers have no means to dissipate any additional heat so they have to be built larger to take advantage of larger wire diameter and to use the added surface area of the transformer to dissipate the heat. This limitation has stagnated present day transformers size and cost. Use of the thermocooler and high modulus carbon graphite laminate material strips together enables the applicant to push electrical inductor designs to higher power levels to meet new and existing applications which need small size and low weight and for overall simpler cooling systems in space, electric automobiles and aviation craft.

16. TECHNICAL EVALUATION OF THE *JAKLIC ET AL. PATENT AS RELATES TO THE ABOVE-STATED APPLICATION*

(A) *Jaklic et al.* teaches the application of on resin coated particles for encapsulating electrical inductive apparatus. The similarity with the above-stated application is that both use a potting compound, but in different ways. *Jaklic et al.* provides a detailed teaching of potting an electrical device using resin coated materials which exhibit a mild degree of thermal conductivity unlike a resin thermal compound having low conductive capabilities. The

Jaklic et al. potting compound is comprised of a basic resin binder with other materials added which exhibit mild thermal conductivity like sand and rounded gravel particles. *Jaklic et al.* also teaches a similar potting compound to that claimed in the above-stated application.

(B) In *Jaklic et al.*, the potting compound completely surrounds the electrical coil and inductor, bonding them all together. This is an important difference between *Jaklic et al.* and the above-stated application. *Jaklic et al.* uses the core material as a temporary heat sink which, over time, becomes hot.

(C) In the above-stated application, the heat from the coil windings is shunted not towards the transformer core material which aids the core in running cooler. The core material is free to float in the bobbin and is not bonded to the coil assembly in any way. The gap between the coil and the core material raises the thermal impedance further reducing any heating effects of the coil on the core material. The inductor core is free to conduct and radiate to free space with no additional thermal restrictions like potting compound. The core temperature is reduced because it's temperature is related to it's core material losses at the switching frequency and not raised by conducting heat from the coil assembly. Core heating drawbacks are not suffered by the above-stated application..

(D) *Jaklic et al.* takes no action t improve the coil windings thermal interface as taught in the above-stated application such as going into the coil inter windings where the heat is generated. *Jaklic et al.* only applies a thermal conductive material to the outside of the coil to conduct the coil surface heat away.

(E) *Jaklic et al.* teaches that reduction of operating temperature of the electrical device by 8°C, whereas experiments have shown that the device taught by the above-stated application shows ~60°C temperature reduction for an operating system.

(F) In *Jaklic et al.*, the materials taught are vastly poorer in thermal conductivity when compared with a high modulus carbon graphite laminate ~24 watts/inch°C. The K_{sand} was ~0.0083 watts/inch°C while the K_{gravel} was ~0.096 watts/inch°C. The high modulus carbon graphite laminate conducts orders of magnitude better than the sand and gravel used by *Jaklic et al.* It is noted in a review of Figure 1 of the above-stated application that by adding the high modulus carbon graphite laminate material at the level, the heat that gets into the core material can be readily removed because a low resistance thermal path to the outside of the core is established. It is also noted that the potting compound in *Jaklic et al.* needs to be thick to accommodate the gravel and sand combination, this increases the thermal path length unlike the above-stated application's potting application which shows a very short length to the base plate in Figure 1.

17. As the person signing below:

I declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful statements may jeopardize the validity of the patent application

or any patent issued thereon.

Date: 2/1/99

William E. Howell